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EXCLUSIVE



Details of revolutionary seamless shift gearbox

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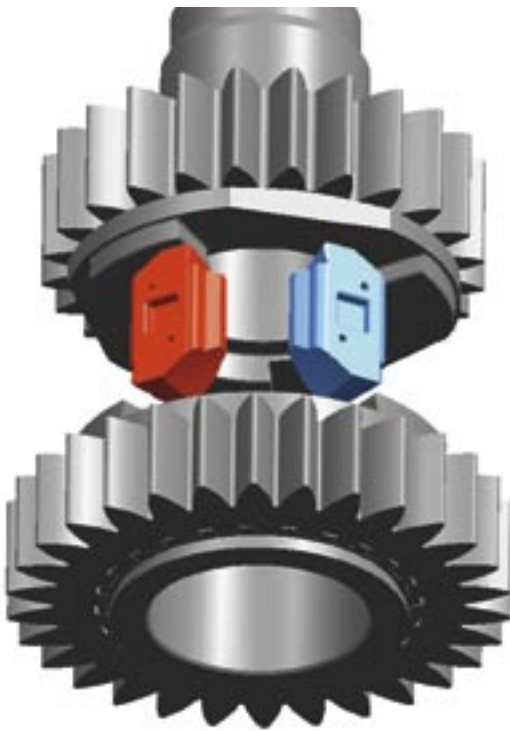


Figure 1: bullets in neutral position between the first and second gear pairs

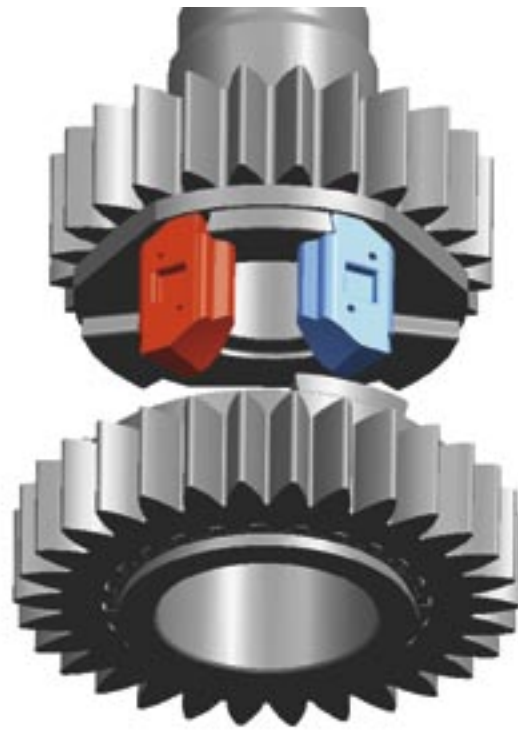


Figure 2: Both bullets in first gear position, allowing minimal backlash

It was in February last year that we broke the story about ZeroShift's revolutionary seamless gearchange system. At the time it was agreed with the company that we wouldn't reveal how the design worked on condition that we could break the story when it was able to go public. It has taken a while but now, for the first time in any magazine in the world, we can reveal the secret of how the ZeroShift system operates. Unless you are extraordinarily patient, you have probably read the panel explaining already. If not, then we urge you to read it and experience that eureka moment, then we can bring you up to date on the company and the latest progress with the system.

When we first visited ZeroShift in late 2003 to research that first feature, the company was very new and very small. It had been founded to develop an invention by one of its founders, Bill Martin. The technology allowed different gear ratios to be selected without any break in the torque delivery from the engine to the wheels. This was ZeroShift and that same principle is still at the core of everything the company is working on today. However, in the intervening period, much else has changed. Initial interest from investors has been turned into a firm financial footing that allows the company to take a more thorough approach to developing the system, rather than rushing to market with a hastily produced product in order to generate funds. It

has also enabled the recruitment of a very well qualified and able team of people to take the idea and transform it into something marketable.

Having read the panel, you may be wondering, with such a simple and elegant principle to work with, what is there to develop? In fact there are

certain issues that come about during the transfer to the real world. The most obvious one is what happens to all that inertia in the engine when you engage a higher ratio? You cannot dissipate 500 to 1000rpm in a millisecond without producing a big impact and ZeroShift's aim is to achieve a flat acceleration curve on a graph.

Current transmissions break the torque during changes, however briefly, resulting in a hole in the curve, while a raw ZeroShift system produces →

Changing strategies

At last we can reveal the revolutionary principle behind the ZeroShift gearbox and how the company has progressed since it was last featured in these pages

Words	Charles Armstrong-Wilson
Images	ZeroShift

“SMOOTHING OUT A SPIKE IS ACHIEVABLE, UNLIKE FILLING IN A HOLE WHICH IS NOT”

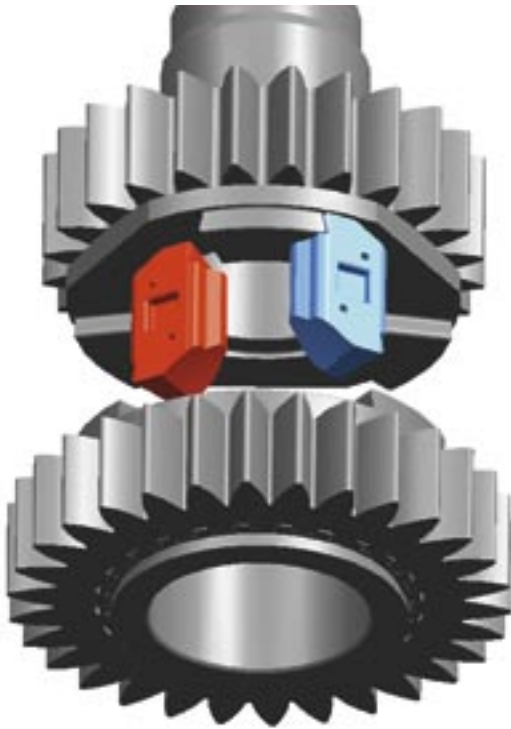


Figure 3: Bullets requested to move across by the selector-mounted springs. Only the unloaded bullets (red) are free to move withdrawing from first gear

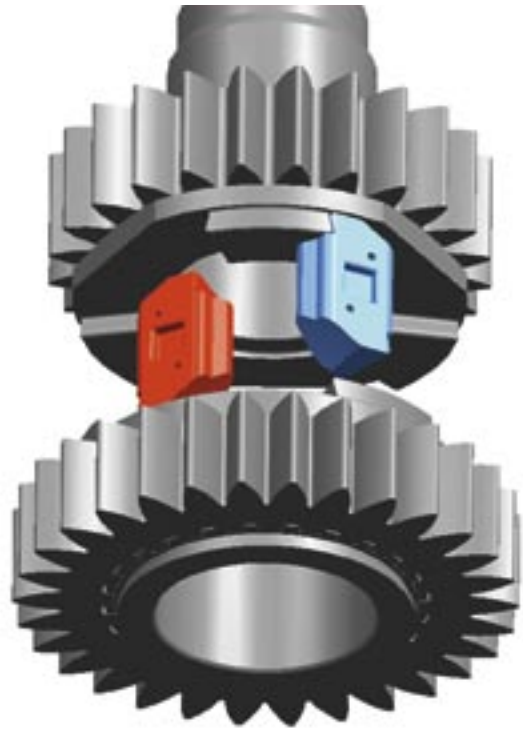


Figure 4: Free bullets (red) slide across to the second gear pair while loaded bullets (blue) remain engaged in first due to retention angle on the dog faces

HOW IT WORKS

ZeroShift is based on a racing-style dog box and could share much of its internals with a typical racing transmission. However, that is not to say it is necessarily crude or difficult to drive in normal traffic. The secret to its operation lies in the ZeroShift hubs that take the place of the dog rings. On a normal dog engagement gearbox, the dog rings typically sit between two gear pairs and slide on the shaft allowing the dogs to engage drive through one gear pair or the other. Obviously, as the ring is pulled out of engagement with one set of dogs, there is a break in the transmission of power before it engages with the other set. If it didn't, then two ratios would be selected at once with explosive results.

In contrast, the ZeroShift hub, instead of having the dogs machined into its faces on either side, has six sliding dogs that the company has christened bullets located in slides around the periphery of the hub (see below). These can be slid from side to side, engaging with either gear pair. This is still very little different to a conventional dog ring. However, where the ZeroShift box differs is in the shape of the bullet ends and the selector mechanism that slides them across. Each bullet has a normal dog profile on one

face and a ramp on the other and the same faces are used the other way round on the other end of the bullet. Also all the bullets are connected to the selector fork via springs.

From neutral (figure 1), the selector fork drags the bullets across to engage with the dogs on the first gear pair (figure 2). Under acceleration, the three dogs on the gear pair will engage with three of the bullets but not with the other three because their faces are ramped and will be thrown out of engagement if they meet. However, on overrun, these three dogs take the drive on their opposite faces.

In an upward change under power, the selector fork will attempt to drag the bullets across to engage with the dogs on the other gear pair (figure 3). But because they are connected to the fork by springs, only the unloaded bullets will move, while the loaded ones will remain engaged with the previous gear pair because the force exerted by the spring is not enough to overcome the clamping force applied to the dogs by the torque of the engine. However, the bullets that were free to move (figure 4) will engage with the dogs on the second gear pair that are turning faster (figure 5). This is the point of ZeroShift where the gearbox is effectively in two gears at once and all hell should be breaking loose. But it doesn't because the second gear pair's higher ratio overdrives the first, releasing the clamping force between the dog faces of the latter and the bullets (figure 6). With the force of the springs still acting on them,

the bullets are free to slide out of engagement and mesh with the dogs on the second gear pair. Should they be slow in coming out of engagement on the first gear pair, then they will catch up with the face of the next dog (figure 7) but, because the other face of the bullet is chamfered, rather than engaging, the dog will hit the ramp and fire the bullet on its way to engage with the other gears. Once all six bullets are engaged with the new gear then drive under power and in overrun is restored (figure 8).

Drive is continuous and unbroken and will not only work between adjacent gear pairs, but also across the gate between non-adjacent pairs, too.



“THIS IS THE POINT OF ZEROSHIFT WHERE THE GEARBOX IS EFFECTIVELY IN TWO GEARS AT ONCE”



Figure 5: Second gear engages with the bullet accelerating the ZeroShift hub



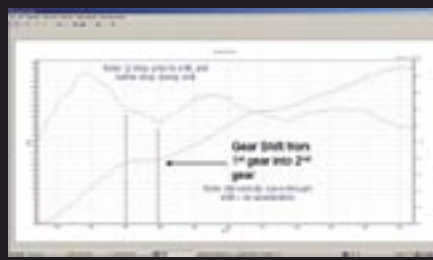
Figure 6: Second gear overdrives first gear unloading the first gear bullet (blue)



Rolls Royce Silver Spirit three-speed auto
During the change the *g* trace exhibits a sharp spike produced by a surge from the engine inertia



Mercedes 320CLK four-speed auto (sports mode)
Dip in the acceleration curve during the change generates a clear plateau on the velocity curve



BMW M3 SMG gearbox
Gradient of the velocity curve drops to zero during the change while the transmission is declutched

a spike as the inertia in the engine delivers a momentary increase in torque while the revs drop to match the road speed in the higher ratio. This is obviously undesirable due to the load it puts on the drivetrain and the tyres. But smoothing out a spike is something that is achievable, unlike filling in a hole which is not.

The team at ZeroShift is working on a number of strategies for smoothing the spike, the simplest of which uses the clutch. By briefly reducing the clamping torque on the plates during the shift, it allows a moment's slip that dissipates the unwanted energy without breaking the transmission of torque to the rear wheels. Other techniques involve cutting the fuel, or spark, or both during a change creating a hole in the engine's torque delivery that can be filled by the unwanted inertia. In addition the company is investigating in-line, driveshaft dampers that can absorb the extra torque, smoothing its impact on the acceleration curve.

The engineers also showed us other idiosyncrasies with the system and various solutions to other issues that appeared during testing that, in the interests of competitive advantage, we have been asked not to reveal. All this may seem a little daunting, but the company has assembled a team of bright, enthusiastic engineers to tackle them. Their backgrounds include Xtrac, Ricardo, Cosworth, Jaguar Racing and Prodrive, and the issue is not so much a lack

of solutions but a question of choosing which ones to follow. Head of design is Miles Ashcroft who has served time at Xtrac, BAR, Nissan and cut his teeth on jet engines. He has been overseeing turning the concept into a practical reality with a view to bringing a product to market.

But in our original feature, we reported that by now the company would already have its first product, an aftermarket version of the T5 gearbox on sale. So what went wrong? Bill Martin is pragmatic and refreshingly honest. 'What happened was two things. First, at that time we didn't know what we didn't know. Secondly, we have taken a more long-term approach to doing things that will take the company toward series production.' The response from

“OUR SYSTEM IS BASED ON CLOSED LOOP CONTROL SO IT IS SELF-TAUGHT”

investors has put them in a much stronger position and the need for a marketable product is not as pressing as was first envisaged. 'We have been spending a lot of time on automating the system and developing control systems.' Work is currently focusing on NVH and FMEA. 'It's been exciting because we're learning quickly.'

The original concept of ZeroShift was for a passive manual system that worked like an ordinary stick-shift gearbox. That was fine until they started to incorporate systems to smooth out the torque spike. Trying to synchronise these electronic shift management systems with the mechanical input from a gear lever proved more difficult than managing the whole process →

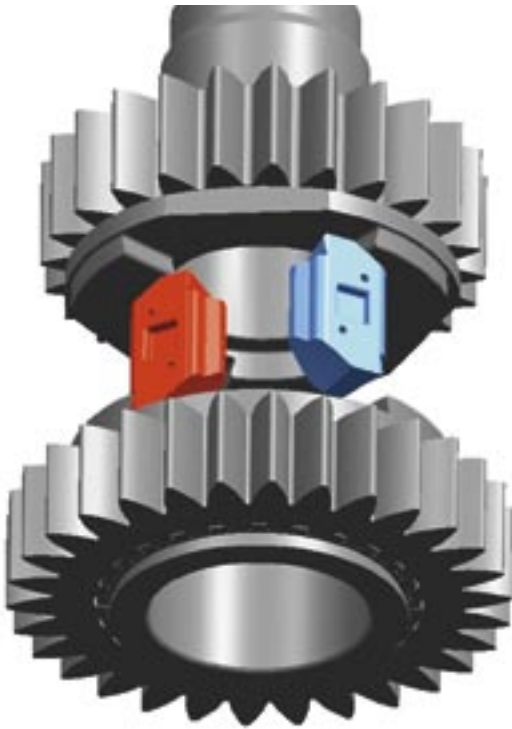


Figure 7: Once unloaded the bullets are withdrawn from first gear by the spring force still being applied from selector fork being pushed toward second gear

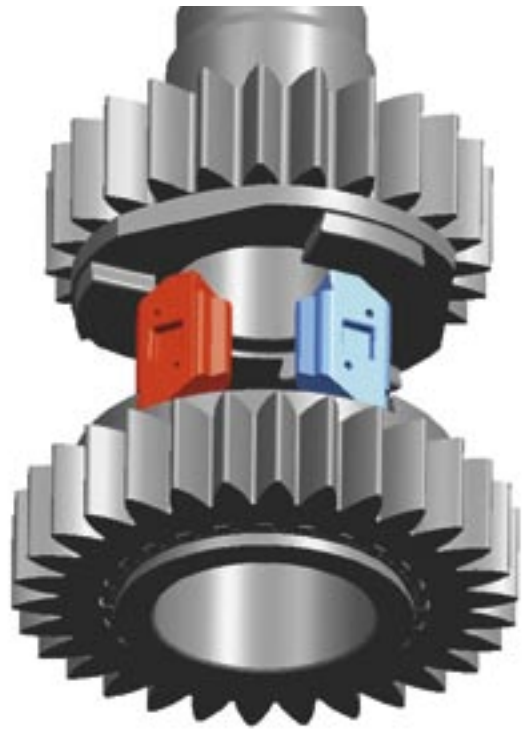
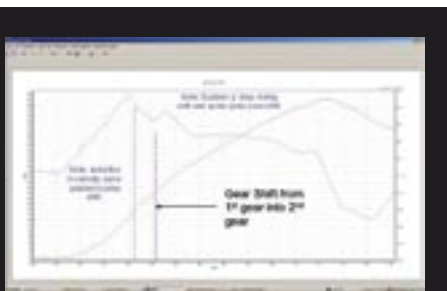


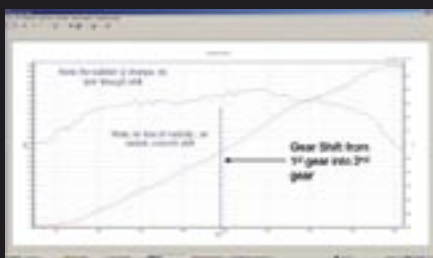
Figure 8: The first gear acceleration bullets become the second gear deceleration bullets as they engage with the second gear dogs



Audi A3 2.0TDI with DSG gearbox (auto mode)
Note the sudden drop in the *g* curve during the shift then a spike on completion of the change



Subaru Impreza 2.0 Turbo with five-speed manual
Classic manual trace with a big drop in *g* during the shift and zero gradient in the velocity curve



TVR Cerbera 4.2 with a ZeroShift gearbox
No dips or spikes in the *g* curve and a velocity curve with a consistent gradient throughout

electronically, so the plan now is to operate the first generation of ZeroShift electronically.

To develop this the company has recruited Andrew Bowyer, an engineer with expertise in industrial automation for manufacturing. Like Martin, he does not have a background in transmissions or even automotive applications so he brings no preconceptions about how things should be done. 'Most car companies are doing it as open loop,' he explains, 'our system is based on closed loop control so it is self taught. The clutch system will be self taught and the cut to the engine will be self taught so it will be constantly changing.' Normally the cost of torque sensors makes this strategy prohibitive, but Bowyer has developed a way of tackling it without one.

This is another unexpected feature of the company, as the core product drives numerous spin-off technologies that ZeroShift is registering with the intention of licensing in the future.

The team obviously has a great deal of talent and experience within it, but the burning question is are they turning ZeroShift into a workable system? Our experience of the company's long-suffering TVR test bed suggests it is. Even with the bare minimum of smoothing strategies in operation the change is only betrayed by a subdued clonk and a barely perceptible surge. It

really is a seamless change with no break in torque delivery, the big giveaway being the lack of acceleration reversal at any point in the change. In fact, when demonstrating ZeroShift to potential customers, the subject of luxury cars as suitable applications is often raised by representatives of car manufacturers. The guests will also ask to be shown the system without the control systems to gauge its appeal to the sports market in its raw form.

So, when can we expect a ZeroShift gearbox on the market? With less need to generate revenue than originally anticipated, the company is taking

more care over its first retail product. The five-speed T5 originally intended as a base is now considered less suitable. Instead work is switching to a production six-speed unit, and the team now expects to have an aftermarket ZeroShift version on the market late in 2006.

And what about its application in

motorsport? The company is currently in talks with a number of outfits and while we were there, Ashcroft gave us a glimpse of a concept for a Formula 1 gearbox. This demonstrated the ability to provide seamless selection of all seven gears in a unit as restricted as the smallest currently in use in F1 today. It seems this dynamic new company has some exciting times ahead.

“THE GEARSHIFT IS ONLY BETRAYED BY A SUBDUED CLONK AND A BARELY PERCEPTIBLE SURGE”

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